Ocean Heat Balance in the ACCESS Ocean Model: Regional variability of dominant mechanisms of heat uptake over the historical period.

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The Australian Community Climate and Earth System Simulator (ACCESS) is being prepared for a forthcoming submission to the Climate Model Intercomparison Project - phase 6 (CMIP6). In addition to the entry-level CMIP6 submission requirements (DECK and historical simulations), we plan for participation in a number of the 21 additional CMIP6 Model Intercomparison Projects (MIPS). Of particular relevance to ocean climate study is participation in the Ocean Model Intercomparison Project (OMIP) and the Flux Anomaly Forced Model Intercomparison Project (FAFMIP). In preparation for the ACCESS submissions, a detailed analysis of the ocean heat budget, and the dominant mechanisms of heat transport is being undertaken with the ACCESS Ocean Model (ACCESS-OM). Ocean heat uptake along with its vertical and lateral redistribution are one of the main factors contributing to the large intermodel spread in the magnitude and regional patterns of sea level rise projections for the 21st century. Here, we perform a heat budget analysis to quantify the physical processes involved in ocean heat uptake and redistribution in contemporary simulations utilising ACCESS-OM. The model is forced with atmospheric reanalyses from the Coordinated Ocean-Sea ice Reference Experiments (CORE-II, 1948-2007) and the Japanese Reanalysis (JRA-55, 1958-2015). Our results show that the global vertical heat balance proposed by Munk (1966) between downward flux by diffusion and upward flux by the mean advection is only held at the tropics and has a small global impact. In the top 500 m, warming from vertical diffusion is balanced by cooling from mixed-layer physics. Below 500 m, regardless of depth level, warming due to mean advection and vertical diffusion counteracts cooling due to isoneutral diffusion and mesoscale eddies. Overall, the global balance is largely dominated by ocean processes in high latitude areas of the North Atlantic and Southern Ocean but with regional differences. The heat balance in the North Atlantic is mostly explained by an advective balance between the mean circulation (warming) and mesoscale eddies (cooling), within the 400-2000 m depth interval. In the Southern Ocean (south of 30˚S), mean advection plays a major role below the mixed layer down to 4000 m, and is mainly counterbalanced by isoneutral diffusion above 900 m and mesoscale eddies below 900 m. We note, however, that within the Southern Ocean, the balancing terms vary depending on latitude band (30˚-45˚S and poleward of 50˚S). The Subantarctic zone holds a similar balance as found in the Southern Ocean despite a stronger advective downward flux above 2000 m, which drives a warming tendency at intermediate depths with significant contribution to the model drift. South of 50˚S, the vertical diffusion of heat changes its sign due to convective processes and cools the ocean interior, resulting in a consistent deep ocean cooling drift which subsequently penetrates into other ocean basins. The subtropics also play a role in the model drift, where a warming trend occurs above 500 m due to intense positive convergence of heat driven by vertical diffusion.

Keywords: Australian Community Climate and Earth System Simulator (ACCESS), Ocean heat uptake, CORE-II, JRA-55-do

Projected sea level rise, gyre circulation and water mass formation in the North Pacific: CMIP5 inter-model analysis

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Spatial dependency of sea level (dynamic sea level; DSL) change attracts much attention, because it directly impacts on the human society. Relatively large sea-level rise is expected to occur in the western North Pacific. It is suggested that wind stress change and heat flux change contribute to DSL change there. However, there is no comprehensive study of DSL dealing with both surface forcings and subsurface ocean using multi-models. In this study, DSL changes over the North Pacific and the associated changes of the subsurface ocean and surface forcings are investigated until 2300 under two greenhouse-gas emission scenarios (RCP4.5, RCP8.5) by analyzing the output from CMIP5 models.
The DSL changes in the North Pacific until 2100 are characterized by a DSL rise in the western North Pacific around the Kuroshio Extension (KE), as also reported by previous studies in both the scenarios. From 2100 to 2300, DSL rises most of the North Pacific with the large positive DSL change located on the KE front only in RCP8.5. DSL changes little after 2100 in RCP4.5 related to the faster stabilization of the radiative forcing than that of RCP8.5. Subsurface density analysis indicates that DSL rise around the KE is associated with decrease in density of subtropical mode water (STMW) and with northward KE migration, while the density decrease of STMW (northward KE migration) is relatively strong between 2000 and 2100 for both RCP4.5 and RCP8.5 (2100 and 2300 for RCP8.5). A large regional density decrease in the STMW is due to a large heat uptake of the STMW related to an excess downward heat flux in the south of the KE. A regional density decreases around the KE front by 2300 induced by the northward migration of the KE, which is related to the northward migration of the zonal wind stress. These features are commonly found in multi-model ensemble means and the relations among representative quantities produced by different climate models.

Keywords: Sea Level, CMIP5 Climate Models, Kuroshio Extension, Subtropical Mode Water

Reduced interdecadal variability of Atlantic Meridional Overturning Circulation under global warming

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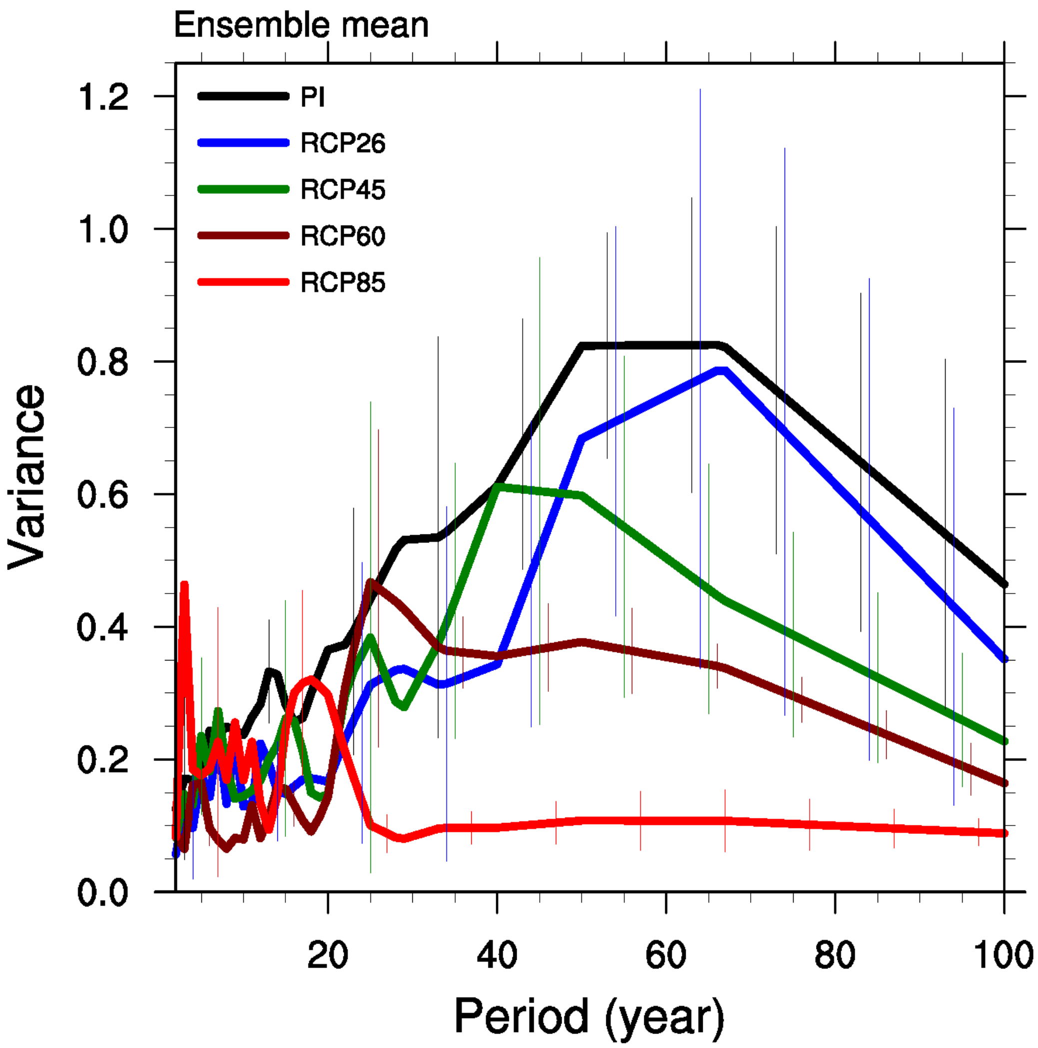
Interdecadal variability of the Atlantic Meridional Overturning Circulation (AMOC-IV) plays an important role in climate variation and has significant societal impacts. Past climate reconstruction indicates that AMOC-IV has likely undergone significant changes. Despite some previous studies, responses of AMOC-IV to global warming remain unclear, in particular regarding its amplitude and time scale. In this study, we analyze the responses of AMOC-IV under various scenarios of future global warming in multiple models and find that AMOC-IV becomes weaker and shorter with enhanced global warming. From the present climate condition to the strongest future warming scenario, on average, the major period of AMOC-IV is shortened from ~50 y to ~20 y, and the amplitude is reduced by ~60%. These reductions in period and amplitude of AMOC-IV are suggested to be associated with increased oceanic stratification under global warming and, in turn, the speedup of oceanic baroclinic Rossby waves.

Keywords: global warming, AMOC, interdecadal variability


Ensemble mean
PI
RCP26
RCP45
RCP60
RCP85
Variance
0.0
0.2
0.4
0.6
0.8
1.0
1.2
20
40
60
80
100
Period (year)

Impacts of interannual ocean circulation variability on Japanese eel larval migration in the western North Pacific Ocean

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The Japanese eel larvae hatch near the West Mariana Ridge seamount chain and travel through the North Equatorial Current (NEC), the Kuroshio, and the Subtropical Countercurrent (STCC) region during their shoreward migration toward East Asia. The interannual variability of circulation over the subtropical and tropical regions of the western North Pacific Ocean is affected by the Philippines–Taiwan Oscillation (PTO). This study examines the effect of the PTO on the Japanese eel larval migration routes using a three-dimensional (3D) particle tracking method, including vertical and horizontal swimming behavior. The 3D circulation and hydrography used for particle tracking are from the ocean circulation reanalysis produced by the Japan Coastal Ocean Predictability Experiment 2 (JCOPE2). Our results demonstrate that bifurcation of the NEC and the strength and spatial variation of the Kuroshio affect the distribution and migration of eel larvae. During the positive phase of PTO, more virtual eels (“v-eels”) can enter the Kuroshio to reach the south coast of Japan and more v-eels reach the South China Sea through the Luzon Strait; the stronger and more offshore swing of the Kuroshio in the East China Sea leads to fewer eels entering the East China Sea and the onshore movement of the Kuroshio to the south of Japan brings the eels closer to the Japanese coast. Significant differences in eel migration routes and distributions regulated by ocean circulation in different PTO phases can also affect the otolith increment. The estimated otolith increment suggests that eel age tends to be underestimated after six months of simulation due to the cooler lower layer temperature. Underestimation is more significant in the positive PTO years due to the wide distribution in higher latitudes than in the negative PTO years.

Keywords: Japanese eel larvae, 3D particle tracking, Western Pacific, PTO, JCOPE2

Studying potential link between phytoplankton and water cloud microphysics at high latitudes using 11 year CALIPSO lidar measurements

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CALIPSO satellite started taking lidar measurements of the atmosphere and ocean since 2006. The lidar measurements provide unique information about high latitude water cloud microphysics (Hu et al., 2007) and ocean subsurface measurements (Behrenfeld et al., 2013; Behrenfeld et al., 2016) all year round. Lidar can make measurements of ocean subsurface at high latitudes all season, including winter, since it provides its own light and it can measure ocean subsurface from holes between clouds (Behrenfeld et al., 2016). Lidar also provide unique water cloud microphysics measurements since its depolarization ratio measurements are sensitive to droplet number concentration and extinction coefficient. This study investigate correlations of high latitude cloud microphysical property anomaly and ocean phytoplankton carbon anomaly during the last 11 years in order to evaluate the link between ocean biogeochemistry and cloud radiative forcing.

Reference:

Behrenfeld, M. J., Y. Hu, C. Hostetler, G. Dall'Olmo, S. D. Rodier et al., 2013: Space-based lidar measurements of global ocean carbon stocks, **GRL**, 40, 4355–4360, doi:10.1002/grl.50816.

Behrenfeld, M, Y. Hu, et al., 2016: Annual boom–bust cycles of polar phytoplankton biomass revealed by space-based lidar, **Nature Geoscience**, DOI: 10.1038/NGEO2861.

Hu, Y., M. Vaughan, C. McClain, M. Behrenfeld et al., 2007: Global statistics of liquid water content and effective number concentration of water clouds over ocean derived from combined CALIPSO and MODIS measurements, **Atmos. Chem. Phys.**, 7, 3353–3359.

Keywords: lidar, cloud, phytoplankton

Ecosystem effects of ocean acidification

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Our oceans cover 70% of the planet, provide 90% by volume of its biosphere, support 50% of global primary production and provide vital ecosystem services, including the recycling of nutrients, carbon sequestration and the provision of protein, on which large proportions of the global population rely. These marine systems are, however, now under threat from both climate (e.g. ocean acidification and global warming) and non-climate stressors (e.g. fishing pressure, invasive species) with negative impacts expected overall for biodiversity, ecosystem functioning, and the goods and services the world’s oceans provide. While there is increasing evidence for the impacts of climate change at the individual level, much less is known about how species’ likely idiosyncratic responses may alter ecological interactions within a community. Given the importance of ecological interactions in structuring marine communities, future climate change is likely to have major consequences for community composition and the structure and function of ecosystems.

My research currently involves carrying out collaborative international research into CO_2 seeps located on Shikine-Jima (Izu Islands, Japan) as a first assessment of the likely ecosystem-level effects of ocean acidification in warm temperate waters –located at a biogeographic boundary where canopy-forming macroalgae and zooxanthellate scleractinian corals coexist. Areas with naturally high seawater pCO_2 can be used as natural laboratories for investigating such long-term (multi-generational) effects of ocean acidification on entire communities. To date, studies at CO_2 seeps have demonstrated a few positive species' responses whereby some organisms can adapt to long-term ocean acidification –some can build their skeletons even faster at higher CO_2 levels –and others have protective tissues that allow them to survive. However, in the majority of cases ocean acidification will reduce the overall biodiversity and the density of marine biogenic habitats and therefore negatively impact the structure and complexity of coastal marine ecosystems. Overall, it is anticipated that it will be a combination of direct effects and community-mediated indirect effects caused by ocean acidification that will drive ecosystem changes in future oceans.

Keywords: Ocean Acidification, CO2 Seeps, Marine Ecosystems, Ecological Interactions, Marine Food Webs

Ocean acidification trend in the Canada Basin since the 2000s

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With the increasing release of anthropogenic carbon dioxide, ocean acidification has been recognized as an important issue in research of global environmental change. Calcium carbonate undersaturation of seawater is one of the most serious threat of ocean acidification. In the Arctic Ocean, known as an extremely sensitive region to ocean acidification, calcium carbonate undersaturation of surface water has been observed in the Canada Basin since 2008. In this study, we have analyzed observations between 2008 and 2016 obtained during the Joint Ocean-Ice Project in the Canada Basin and have found that calcium carbonate saturation state in surface water does not grow steadily worse with the continuing increasing of atmospheric CO_2. The sharp drop in sea ice coverage in 2007-2008 induced a great mount of fresh water discharge into the surface of Canada basin, which accounted for the decrease of calcium carbonate undersaturation. However, after 2009, sea ice coverage decline has slackened and a net export of freshwater to outside of the Canada Basin or to deeper layers has increased salinity and alkalinity of the surface water. This resulted in a rebound in calcium carbonate saturation state in surface water after 2009, transient good news for the marine ecosystem in the arctic.

Keywords: Ocean acidification, Calcium carbonate saturation state, Rebound, Sea ice melt, Arctic Ocean

Response of sea surface fugacity of CO_2 to the Southern Annular Mode (SAM) shift south of Tasmania

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Using observational data collected south of Tasmania during 14 austral summer cruises during 1993-2011, we examined the response of sea surface fugacity of carbon dioxide (fCO_2) to the Southern Annular Mode (SAM) shift, which occurred around 2000. In the southern part of the Southern Ocean (SO) or the Polar Zone (PZ) and the Polar Frontal Zone (PFZ), fCO_2 increased faster at the sea surface than in the atmosphere before the SAM shift, but not after the shift. In the northern part of the SO or the Sub-Antarctic Zone (SAZ), however, surface fCO_2 increased faster than atmospheric fCO_2 both before and after the shift. The SAM shift had an important influence on the surface fCO_2 trend in the PZ and PFZ, but not in the SAZ, which we attribute to differences in regional oceanographic processes (upwelling vs. non-upwelling). The SAM shift may have reversed the negative trend of SO CO_2 uptake.

Keywords: Southern Ocean, Southern Annular Mode shift, Carbon cycling

Coupling of Surface Ocean Heat and Carbon Perturbations under Global Warming

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The ocean is the principal integrator in the climate system on multi-decadal to centennial timescales, modeling anthropogenic climate change by absorbing approximately 30% of anthropogenic carbon (C_{ant}) emissions. Under global warming, coupled climate model simulations and theoretical arguments indicate that the capacity of the ocean to absorb C_{ant} will be reduced relative to what would be absorbed for an unperturbed physical state of the ocean, with this constituting a positive ocean carbon-climate feedback. Recent studies emphasize the importance of the North Atlantic and/or the Southern Ocean in sustaining such feedbacks. Here we use simulations with an Earth system model under a "business-as-usual" (historical/RCP8.5) concentration pathway to show that the coupling of heat and carbon in surface waters of the low-latitude shallow overturning circulation plays a first-order role in sustaining global ocean carbon-climate feedbacks. For an approximately 2°C average warming over 45°S-45°N, solubility perturbations alone would be expected to produce an 8% increase in surface ocean pCO_2. The fact that the increase in pCO_2 is only 2% by the end of the 21st century indicates that the response is more nuanced than just a solubility response. The amplitude of the surface warming prescribes a reduction of surface DIC concentrations of approximately 6 mmol/kg/°C, resulting in an 8% reduction in surface DIC concentrations relative to what one would expect in the absence of warming by the end of the 21st century. The reduction by 8% in surface DIC concentrations over 45°S-45°N constitutes a positive carbon-climate feedback. The consistency of this 8% reduction in average surface ocean DIC concentrations and the time-integrated reduction by 8% in spatially integrated CO_2 uptake by the ocean over the same latitude band indicates that it is the perturbations to the buffering capacity of seawater rather than perturbations to ocean ventilation rates that determine the amplitude of the carbon-climate feedbacks over 45°S-45°N. This stands in contrast to the drivers of carbon-climate feedbacks over the high latitudes, which tend to be driven by ocean circulation changes perturbing the natural carbon cycle.

Keywords: Carbon cycle, Earth system model, Carbon-climate feedback

Uncertainty in Detecting Trend: A New Criterion and Its Applications to Global SST

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In most parts of the global ocean, the magnitude of the long-term linear trend in sea surface temperature (SST) is much smaller than the amplitude of multi-scale internal variation. One can thus use a specific period in a much longer record to arbitrarily determine the sign of long-term trend, which is statistically significant, in regional SST. This could lead to a controversial conclusion on how global SST responded to the anthropogenic forcing in the recent history.
In this study, the uncertainty in the linear trend due to multi-scale internal variation is theoretically investigated. It is found that the “estimated” trend will not change its sign only when its magnitude is greater than a theoretical threshold that scales the influence from the multi-scale internal variation. Otherwise, the sign of the “estimated” trend may depend on the period used. The new criterion is found to be superior over the existing methods when the de-trended time series is dominated by the oscillatory term. Applying this new criterion to a global SST reconstruction from 1881 to 2013 reveals that the influences from multi-scale internal variation on the sign of “estimated” linear trend cannot be excluded in most parts of the Pacific, the southern Indian Ocean and the northern Atlantic; therefore, the warming or/and cooling trends found in these regions cannot be interpreted as the consequences of anthropogenic forcing. It’s also suggested that the recent hiatus can be explained by combined uncertainty from internal variations at the interannual and decadal time scales.

Keywords: ordinary least-square, linear trend, internal variation

